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(54) Title: DETECTOR AND METHOD FOR DETECTION OF IONIZING RADIATION
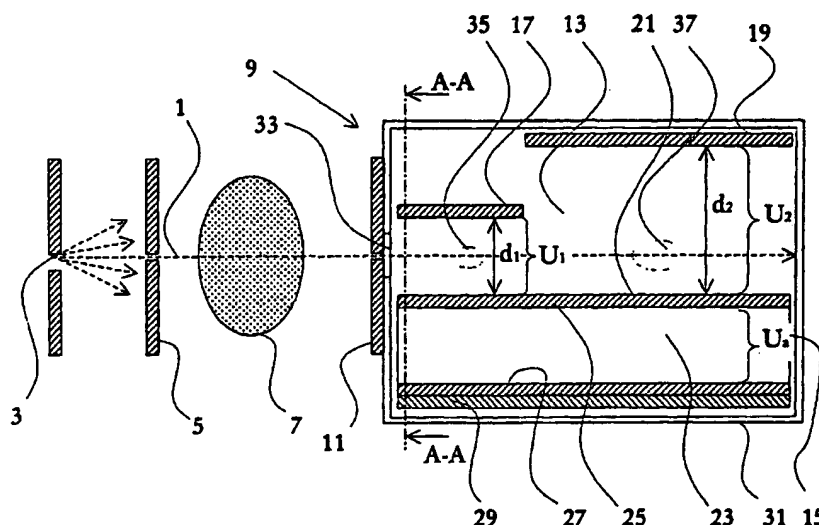
(57) Abstract: A detector comprises a chamber (13) filled with an ionizable substance, a first (17, 19) and a second (21) electrode arranged such that radiation (1) can enter the chamber between and parallel with the first and second electrodes and become ionized, an electron avalanche amplifier, and a read-out arrangement (29), wherein the electrodes are adapted to drift electrons created during ionization, the avalanche amplifier is adapted to amplify the electrons and the read-out arrangement is adapted to detect the electron avalanches. The chamber is designed such that radiation entering the chamber will firstly enter a first chamber section having a first distance ($d_1$) between the electrodes and then enter a second chamber section having a second distance ($d_2$) between the electrodes, where the first and second distances are different, and the read-out arrangement is arranged such that electron avalanches derivable from ionization in the respective chamber section are separately detectable.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

# DETECTOR AND METHOD FOR DETECTION OF IONIZING RADIATION

## TECHNICAL FIELD OF THE INVENTION

The present invention generally relates to the detection of ionizing radiation, and particularly to the detection of X-rays.

5   More specifically, the invention relates to a detector for detection of ionizing radiation, to a device for use in planar beam radiography, and to a method for detection of ionizing radiation.

## DESCRIPTION OF RELATED ART AND BACKGROUND OF THE INVENTION

10   Gaseous detectors, in general, are very attractive at photon energies lower than approximately 10 keV. The main advantages of gaseous detectors are that they are cheap to manufacture compared to solid state detectors, and that they can employ gas multiplication to strongly (on orders of magnitude) amplify the
15   signal amplitudes. However, at energies exceeding 10 keV the gaseous detectors are less attractive as the stopping power of the gas decreases rapidly with increased photon energy. This results in a heavily deteriorated spatial resolution due to extended tracks of so-called long-range electrons, which are
20   created as a result of the X-ray absorption.

An improved spatial resolution is achieved by a gaseous detector for use in planar beam radiography, in which electrons released by interactions between photons and gas atoms can be extracted in a direction essentially perpendicular to the incident radiation.
25   A detector of such a kind is described in our copending international application No. PCT/SE98/01873 entitled *A method and a device for planar beam radiography and a radiation detector* and filed on October 19, 1998. Another detector is depicted in the US patent No. 5,521,956 issued to Charpak.

When designing a detector for photons of lower energies and using
X-rays irradiation of an energy range that includes both lower
and higher energies, the higher energy photons will only to a
lesser degree be absorbed in the detector due to the relatively
5    short length of the detector.

In some situations, however, it is desirable to also detect high-
energy photons as these can carry information that is distinct
from that of lower energy photons. For instance, in the field of
radiology the absorption coefficients for bone and tissue,
10   respectively, vary quite differently with photon energy.

## SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide
a detector for detection of ionizing radiation, which employs
avalanche amplification, and can operate in a wider energy range,
15   particularly also at higher energies, of incoming radiation than
prior art detectors.

It is in this respect a particular object of the invention to
provide such a detector that provides for an improved spatial
resolution and particularly for an improved energy resolution.

20   A further object of the present invention is to provide a
detector for detection of ionizing radiation, which is effective,
fast, accurate, reliable, easy to install and use, and of low
cost.

Still a further object of the invention is to provide a detector
25   for detection of ionizing radiation, which is sensitive and can
thus operate at very low X-ray fluxes.

Yet a further object of the invention is to provide a detector
for detection of ionizing radiation, which can be given a length,
in the direction of the incoming radiation, for achieving a
30   desired stopping power, which makes it possible to detect a major
portion of the incoming radiation.

Still a further object of the invention is to provide a detector for detection of ionizing radiation, in which electrons released by interactions between photons and gas atoms can be extracted in a direction essentially perpendicular to the incident radiation.

5 Hereby it is possible to obtain a particularly high spatial resolution.

Yet a further object of the invention is to provide a detector for detection of ionizing radiation, which can operate at high X-ray fluxes without performance degradation and has a long

10 lifetime.

Still a further object of the invention is to provide a detector for detection of any kind of ionizing radiation, including electromagnetic radiation as well as incident particles, including elementary particles.

15 These objects among others are, according to a first aspect of the invention, attained by a detector as claimed in Claim 1, and, according to a second aspect of the invention, attained by a detector as claimed in Claim 26.

It is a further object of the present invention to provide a

20 device for use in planar beam radiography, e.g. slit or scan radiography, comprising at least one detector according to the first aspect of the invention.

It is in this respect a particular object of the present invention to provide such a device that can be operated such that

25 an object to be imaged only needs to be irradiated with a low dose of X-ray photons, while an image of high quality is obtained.

Still a further object of the invention is to provide a device for use in planar beam radiography, in which a major fraction of

30 the X-ray photons incident on the detector can be detected, for

further counting or integration in order to obtain a value for each pixel of the image.

Yet a further object of the invention is to provide a device for use in planar beam radiography, in which image noise caused by radiation scattered in an object to be examined is strongly reduced.

Still a further object of the invention is to provide a device for use in planar beam radiography, in which image noise caused by the spread of X-ray energy spectrum is reduced.

Yet a further object of the present invention is to provide a device for use in planar beam radiography, which can operate at high X-ray fluxes without performance degradation and has a long lifetime.

These objects among others are, according to a third aspect of the invention, attained by a device as claimed in Claim 18, and, according to a fourth aspect of the invention, attained by a device as claimed in Claim 36.

It is a further object of the present invention to provide a method for detection of ionizing radiation, which employs avalanche amplification and is efficient in a wider energy range, particularly also at higher energies, of incoming radiation than prior art methods.

It is in this respect a particular object of the invention to provide such a method that provides both for an improved spatial resolution and for an improved energy resolution.

A further object of the present invention is to provide a method for detection of ionizing radiation, which is effective, fast, accurate, reliable, easy to perform, and which can be implemented in a simple and cost effective way.

Still a further object of the invention is to provide a method for detection of ionizing radiation, which is sensitive and can thus operate at very low X-ray fluxes.

Yet a further object of the invention is to provide a method for
5   detection of ionizing radiation, which detects a major portion of the incoming radiation.

Still a further object of the invention is to provide a method for detection of ionizing radiation, in which electrons released by interactions between photons and gas atoms can be extracted in
10  a direction essentially perpendicular to the incident radiation. Hereby it is possible to obtain a particularly high spatial resolution.

Yet a further object of the invention is to provide a method for detection of ionizing radiation, which can be performed using
15  high X-ray fluxes.

Still a further object of the invention is to provide a method for detection of any kind of ionizing radiation, including electromagnetic radiation as well as incident particles, including elementary particles.

20  These and other objects are, according to a fifth aspect of the present invention, attained by a method as claimed in Claim 22, and, according to a sixth aspect of the invention, attained by a method as claimed in Claim 37.

Further characteristics of the invention and advantages thereof
25  will be evident from the following detailed description of preferred embodiments of the invention, which are shown in the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the
30  detailed description of embodiments of the present invention

given hereinbelow and the accompanying Figs. 1-7, which are given by way of illustration only, and thus are not limitative of the invention.

5    Fig. 1 illustrates schematically, in a cross sectional view, a device for planar beam radiography, according to an embodiment of the invention.

Fig. 2 is a diagram showing the mean free path of X-rays due to absorption in argon, krypton, and xenon, respectively, as a function of X-ray energy at standard temperature and pressure
10   (STP).

Fig. 3 is a diagram showing the practical interaction range of electrons due to scattering in argon, krypton, and xenon, respectively, as a function of electron energy at standard temperature and pressure (STP).

15   Fig. 4 is a diagram showing the absorption coefficient of X-rays due to absorption in tissue and bone, respectively, of human body as a function of X-ray energy.

Fig. 5 is a schematic, partly enlarged, cross sectional view of a particular embodiment of the invention, taken along A-A of Fig.
20   1.

Fig. 6 is a schematic view of an embodiment of an X-ray source and an electrode formed by segmented read-out strips in accordance with the present invention.

Fig. 7 is a schematic cross sectional view of a device with
25   stacked detectors for use in planar beam radiography according to a further embodiment the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the following description, for purposes of explanation and not limitation, specific details are set fourth, such as particular

techniques and applications in order to provide a thorough
understanding of the present invention. However, it will be
apparent to one skilled in the art that the present invention may
be practiced in other embodiments that depart from these specific
5    details. In other instances, detailed descriptions of well-known
methods and apparatuses are omitted so as not to obscure the
description of the present invention with unnecessary details.

Fig. 1 is a sectional view in a plane orthogonal to the plane of
a planar X-ray beam 1 of a device for planar beam radiography,
10   according to an embodiment of the present invention. The device
includes an X-ray source 3, which together with a first thin
collimator window 5 produces the planar fan-shaped X-ray beam 1,
for irradiation of an object 7 to be imaged. The first thin
collimator window 5 can be replaced by other means for forming an
15   essentially planar X-ray beam, such as an X-ray diffraction
mirror or an X-ray lens etc.

The beam transmitted through the object 7 enters a detector 9.
Optionally a thin slit or second collimator window 11, which is
aligned with the X-ray beam, forms the entrance for the X-ray
20   beam 1 to the detector 9.

A major fraction of the incident X-ray photons are detected in
the detector 9, which includes a chamber 13, means for electron
avalanche amplification 15, and a read-out arrangement 29. The
detector 9 is oriented such that the X-ray photons enter sideways
25   between a first 17, 19 and a second 21 electrode arrangement
between which a voltage $U_1$, $U_2$, i.e. an electric field, for drift
of electrons and ions in the chamber 13, is applied.

The first drift electrode arrangement 17, 19, is comprised of a
first 17 and a second 19 cathode plate, respectively, and the
30   second drift electrode arrangement is comprised of an anode plate
21. Voltage $U_1$ is applied between cathode plate 17 and anode
plate 21, and voltage $U_2$ is applied between cathode plate 19 and
anode plate 21. $U_1$ and $U_2$ may be equal, but $U_2$ is preferably larger

than $U_2$ in order to create an electric field of constant amplitude in chamber 13. The electrode arrangements are preferably mutually substantially parallel and separated by a short distance $d_1$ in a first section of chamber 13, i.e. between

5    cathode plate 17 and anode plate 21, and by a longer distance $d_2$ in a second section of chamber 13, i.e. between cathode plate 19 and anode plate 21. This will be discussed further below.

Chamber 13 is a conversion and drift volume and is filled with an ionizable gas. The radiation entered into chamber 13 ionizes the

10   gas and the electrical field created by $U_1$ and $U_2$ results in a drift field in region 13 causing drift of electrons towards anode plate 21, and thus towards avalanche amplification means 15, and drift of ions towards cathode plates 17 and 19.

Chamber 13 is filled with a gas, which can be a mixture of for

15   example 90% krypton and 10% carbon dioxide or a mixture of for example 80% xenon and 20% carbon dioxide. The gas can be under pressure, preferably in a range 1-20 atm. Therefore, the detector includes a gas tight housing 31 with a slit entrance window 33, through which the X-ray beam 1 enters the detector. The window is

20   made of a material, which is transparent to the radiation, e.g. Mylar®, or a thin aluminum foil. This is a particularly advantageous additional effect of the invention, detecting sideways incident beams in a gaseous avalanche detector 9, compared to previously used gaseous avalanche chambers, which

25   were designed for radiation incident perpendicular to the anode and cathode plates, requiring a window covering a large area. The window can in this way be made thinner, thus reducing the number of X-ray photons absorbed in the window.

In operation, the incident X-rays 1 enter the detector through

30   the optional thin slit or collimator window 11, if present, and between cathode plate 17 and anode plate 21, preferably in a center plane between these as indicated in Fig. 1. The incident X-rays 1 then travel through the gas volume in a direction

preferably substantially parallel with electrode plates 17, 19, and 21 and get absorbed, thus ionizing gas molecules in chamber 13.

5      The electron avalanche amplification means 15 is arranged such that the released electrons will drift towards and enter an electron avalanche amplification volume 23 of amplification means 15, preferably through an avalanche cathode arrangement 25, and wherein they will be multiplied by means of a voltage $U_a$ being applied between said avalanche cathode arrangement 25 and an
10     avalanche anode arrangement 27.

Voltage $U_a$ is applied between the avalanche cathode and the avalanche anode such that electrons from chamber 13 passing avalanche cathode 23 is accelerated towards avalanche anode 27, resulting in electron multiplication and thus multiple avalanche
15     electrons reach avalanche anode 27. In connection with the avalanche anode 27 a read-out arrangement 29 is provided for detection of a pulse induced by the electron avalanches. In such manner single-photon detection may be realized.

Preferably, the read-out arrangement 29 also constitutes the
20     avalanche anode electrode 27 and hence arrangements 29, 27 are integrated into a single element. Alternatively, the read-out arrangement 29 can be formed in connection with other parts of electron avalanche amplification means 17 or in connection with the drift cathode plates 17, 19. It can also be formed separated
25     from the anode or cathode arrangements by a dielectric layer or substrate (not shown in Fig. 1). In such a case it is necessary that the anode or cathode arrangements is semi-transparent to induced pulses, e.g. formed as strips or pads. With reference to Fig. 6 different possible read-out arrangements 15 are further
30     discussed.

The X-ray source 3, the first thin collimator window 5, the optional collimator window 11 and the detector 9 are connected

and fixed in relation to each other by a suitable means for example a frame or support (not shown in Fig. 1).

The so formed device for radiography can be moved as a unit to scan an object, which is to be examined. In a single detector
5    system, as shown in Fig. 1, the scanning can be done by a pivoting movement, rotating the unit around an axis through for example the X-ray source 3 or the detector 9. The location of the axis depends on the application or use of the device, and possibly the axis can also run through the object 7, in some
10   applications. It can also be done in a translative movement where the detector and the collimator are moved, or the object to be imaged is moved. In a multiline configuration, where a number of detectors are stacked, as will be explained later, in connection with Fig. 7, the scanning can be performed in various ways. In
15   many cases it can be advantageous if the device for radiography is fixed and the object to be imaged is moved.

As already mentioned, the X-rays enter the detector preferably in a direction parallel to cathode plate 17 and anode plate 21. In this way the detector can easily be made with an interaction path
20   long enough to allow a major fraction of the incident X-ray photons to interact and be detected. The length of detector 9 and of cathode plates 17 and 19 in a direction parallel with the incident radiation will be further discussed below.

When an X-ray photon hits and interacts with an atom of noble
25   gas, a hole in the K or L shell is created, and a photoelectron having the kinetic energy $E = h\nu - E_{shell}$ is released. Where inside chamber 13 this interaction takes part is governed statistically by the absorption rate of the X-rays in the gas or gas mixture that is used. Fig. 2 is a diagram showing the mean free path $\lambda$ of
30   X-rays due to absorption in argon, Ar, krypton, Kr, and xenon, Xe, respectively, as a function of X-ray energy $h\nu$ at standard temperature and pressure (STP). In the diagram, the mean free

path varies from 0 to 70 cm as the X-ray photon energy varies from 0 to 50 keV.

The detector in accordance with the present invention is particularly useful when broadband X-ray radiation is used.
5    Hence, photoelectrons of a large range of kinetic energy are released. Electrons having lower kinetic energy are denoted short-range electrons, as such electrons have a rather short mean free path, and electrons of higher kinetic energy are correspondingly denoted long-range electrons.

10   A long-range electron is thus an electron with high kinetic energy (up to 100 keV), which will travel a relatively long path (1-20 mm at 1 atm.) before it becomes retarded and stopped (looses its kinetic energy) in the gas. Fig. 3 is a diagram showing the practical interaction range $\delta_e$ of electrons due to
15   scattering in argon, Ar, krypton, Kr, and xenon, Xe, respectively, as a function of electron energy $E_e$ at standard temperature and pressure (STP). In the diagram, the interaction length of the electrons varies from 0 to 5 cm as the electron energy varies from 0 to 50 keV.

20   When the hole in the K or L shell is filled by an electron from a higher level, an Auger electron and/or a fluorescent (X-ray) photon will appear. An Auger electron is a short-range electron.

A short-range electron is an electron with low kinetic energy (typically 1-5 keV), which will travel a relatively short path
25   (0.01-0.1 mm at 1 atm.) before it becomes stopped (looses its kinetic energy) in the gas or gas mixture.

Therefore, during one single interaction of an X-ray photon with a gas atom, e.g. Kr or Xe, several electrons will in many cases be released simultaneously; both long-range and short-range
30   electrons. Further, fluorescent photons may be emitted during the interaction.

Both long-range and short-range electrons produce electron tracks of secondary ionized electrons produced by the electrons during the travel in the gas. When an electron has rather high kinetic energy (e.g. 20-30 keV), the number of released electrons
5    (secondary ionized electrons) is low per path unit. For electrons having low kinetic energy (typically 1-4 keV) the number of released electrons (secondary ionized electrons) per path unit is higher.

As mentioned, the typical track length of a long-range electron
10   is about 1-20 mm at atmospheric pressure. This is therefore a physical limit of the spatial resolution. The fluorescent photons emitted also create ionization, as mentioned above. This ionization takes place far away from the primary interaction with a typical attenuation length of 1.5-250 mm at atmospheric
15   pressure. This ionization also deteriorates the spatial resolution and creates background noise.

By detecting all electrons including those released from ionization by fluorescent photons, which is done at present in all existing gas detectors, spatial resolution is drastically
20   deteriorated at photon energies above 10 keV. All electrons are detected since the electrode gap is large.

Typically between a few hundred and thousand secondary ionization electron-ion pairs are produced from a single 20 keV X-ray photon in this process. The secondary ionization electrons (together
25   with the primary ionization electron) will drift towards the electron avalanche amplification means 17 due to the electric field in the conversion and drift volume 13. When the electrons enter regions of focused field lines of the electron avalanche amplification means 17 they will undergo avalanche amplification.

30   The movements of the avalanche electrons and ions induce electrical signals in the read-out arrangement 29 for detection of electron avalanches. The read-out arrangement 29 is preferably arranged in vicinity of electron avalanche anode 27, but the

signals may be picked up elsewhere, such as e.g. close to cathode plates 17 and 19 or at avalanche cathode 25, or at a combination of two or more of said locations. The signals are further amplified and processed by read-out circuitry (not shown in Fig.

5    1) to obtain accurate measurements of the X-ray photons. The read-out arrangement 29 is arranged such that electron avalanches derivable mainly from ionization in the respective chamber section (i.e. between cathode plate 17 and anode plate 21, e.g. at 35, and between cathode plate 19 and anode plate 21, e.g. at

10   37) are separately detectable. Hence, a detector 9 for energy resolved detection of X-rays is achieved, wherein, at least from a statistical viewpoint, X-rays of lower energies are absorbed in the first section of chamber 13 having a short distance $d_1$ between the electrode plates and X-rays of higher energies are

15   absorbed in the second section of chamber 13 having a distance $d_2$ between the electrode plates.

The electrode distance $d_1$ in the first chamber section is preferably chosen such that detection of lower energy photons of high spatial resolution is enabled. Thus, $d_1$ shall preferably be

20   shorter than the attenuation length of the fluorescent (X-ray) photons. This results in that a great number of fluorescent photons will not cause ionization in the conversion and drift volume.

A further improvement of the spatial resolution is achieved if

25   the detector is provided with a first chamber section having an electrode gap distance $d_1$, which is shorter than the length of the electron tracks (i.e. the interaction length) of long-range electrons. This results in that an even larger number of fluorescent photons and a large number of long-range electrons

30   will not undergo full energy loss in the first chamber section.

The distance $d_1$ may preferably be selected such that a major portion of the fluorescent photons and/or long-range electrons are discriminated. That is, a major portion of the fluorescent

photons will not cause ionization in the conversion and drift gap and/or a major portion of the long-range electrons will not be retarded to the energy level where they produce a high number of secondary ionized electrons per path unit within the first
5   chamber section.

Still a further improvement of the spatial resolution is achieved if the detector is provided with a first chamber section having an electrode gap distance $d_1$, which is essentially a few times the length of the electron tracks (i.e. interaction length) of
10   short-range electrons, e.g. 1-5 times the length of the electron tracks of the short-range electrons. This results in that a larger number of fluorescent photons and a larger number of long-range electrons will not undergo full energy loss in the conversion and drift volume. Of course the distance $d_1$ can be
15   smaller than the length of the electron tracks of the short-range electrons, but then the efficiency will go down since also short-range electrons will reach the electrode plates before complete ionization.

By such geometrical discrimination of long-range electrons and
20   fluorescent photons it is achieved that a larger amount of the detected avalanches are caused by short-range electrons, than without the discrimination. This improves the spatial resolution since the long-range electrons and fluorescent photons cause avalanches far from the interaction position of the incident X-
25   ray. The more long-range electrons and fluorescent photons that are discriminated, the higher the ratio between detected avalanches caused by short-range electrons and detected avalanches caused by long range electrons and fluorescent photons will be. A higher spatial resolution is hereby achieved.

30   The length $l_1$ of the first chamber section in the direction of the incident X-rays is arranged such that a substantial portion of the lower energy radiation is absorbed in the first chamber section.

The electrode distance $d_2$ in the second chamber section is preferably chosen such that detection of higher energy photons is enabled. Thus, $d_2$ shall preferably be substantially longer than $d_1$ in order to allow primary long-range electrons to be retarded

5    and to ionize gas molecules, thus releasing shorter-range electrons. The efficiency of detecting higher energy photons is thus improved to the cost of a deteriorated spatial resolution.

Preferably though, the electrode distance $d_2$ in the second chamber section is shorter than the attenuation length of the

10   fluorescent (X-ray) photons. This results in that a great number of fluorescent photons will not cause ionization in the conversion and drift volume.

A further improvement of the spatial resolution is achieved if the detector is provided with a second chamber section having an

15   electrode gap distance $d_2$, which is essentially a few times the length of the electron tracks (i.e. interaction length) of long-range electrons, e.g. 1-5 times the length of the electron tracks of the long-range electrons.

The length $l_2$ of the second chamber section in the direction of

20   the incident X-rays is arranged such that a substantial portion of the higher energy radiation is absorbed in the second chamber section.

Certainly, the electrode distances $d_1$ and $d_2$, and the chamber section lengths $l_1$ and $l_2$ are chosen for each particular

25   application and for each particular radiation spectrum used in order to achieve desired detection efficiency, and required spatial and energy resolution.

Also electronic discrimination can be used to improve the spatial resolution and the energy resolution. As mentioned, short-range

30   electrons produce a high number of secondary ionized electrons per path unit, and electrons having high energy produce a low number of secondary ionized electrons per path unit. Therefore

the avalanche-amplified pulses at the read-out arrangement are high and/or wide for short-range electrons, while they are small for a long-range electron in the first chamber section. By providing the read out electronics with a threshold function as

5      regards some suitable signal derived parameter, e.g. amplitude or integrated value, the pulses from the long-range electrons in the first chamber section can be electronically discriminated and hence both the spatial resolution and the energy resolution are further improved.

10     Similarly, in the second chamber section, the high-energy electrons are allowed to be fully retarded, and hence in total a larger number of electrons is released from such electrons than from short-range electrons and therefore the detected avalanche amplified pulses are higher and/or wider for longer-range

15     electrons than for shorter-range electrons. Thus, as higher-energy photons produce longer-range electrons the energy resolution in the second chamber section may be further improved by electronically discriminating pulses having a signal-derived parameter, e.g. amplitude or integrated value, below a certain

20     threshold value.

In yet another embodiment of the present invention the first and second chamber sections are separated in a fluid-tight, but radiation permeable, manner (not shown in fig. 1) and each chamber is individually filled with an ionizable gas of a

25     predetermined pressure. The chamber sections may be separated by a fluid-tight wall in which a suitable radiation transparent window is arranged (similar to window 33), through which window the X-ray beam 1 enters the second chamber section. By controlling the content of the gas mixture and the gas pressure

30     in each chamber individually a further improved energy and spatial resolution may be achieved.

With reference now to Fig. 4 a particular embodiment of the present invention is to be described, wherein it can be used to

measure the bone mineral density of humans. Fig. 4 is a diagram showing the absorption coefficient $\alpha$ of X-rays due to absorption in tissue, and in bone, respectively, of human body as a function of X-ray energy. In the diagram, the absorption coefficient

5      varies from 1 to roughly 0.4 as the X-ray photon energy varies from 0 to 150 keV. Shown is also the differential absorption coefficient (indicated Tissue-Bone), which is an indication of the absorption selectivity between tissue and bone, as a function of the photon energy.

10     Normally the bone is surrounded by an unknown amount of tissue. One commonly used method to estimate the amount of bone is to detect transmitted X-rays at two different X-ray energies. One exposure is made at X-ray energies where bone and tissue absorb X-rays very differently; typically at 40 keV where the

15     differential absorption coefficient has a maximum, see Fig. 4. Another exposure is made at energies where bone and tissue absorb X-rays in a similar way; typically at energies above 100 keV, see Fig. 4 again. From these two measurements the amount of bone is estimated. However, this requires that the detector is capable of

20     detecting low energy (around 40 keV) X-rays as well as high energy X-rays (>100 keV), which is often a problem. Furthermore, to obtain beams with a narrow energy distribution at low energy, the incoming X-ray flux, which has a broad spectrum, needs to be heavily filtered, putting a large load on the X-ray tube. The two

25     separate exposures, taken at different times, also give rise to problems due to movements of the object between the two exposures.

The present invention describes a detector and a method that can measure X-rays over a wide energy range. Low energy X-rays are

30     preferably detected in the first, thin chamber section of the detector due to their short absorption length. High energy X-rays mainly traverse the first chamber section of the detector and are detected in the second, thicker chamber section. The invention allows the same detector to be used to efficiently detect X-rays

at rather different energies with the same detector, using the commonly used double exposure method.

Alternatively, the two measurements can be made simultaneously using a broad X-ray spectrum of the incident X-rays. This second
5    alternative requires less filtering of the X-rays and put less load on the X-ray tube. Furthermore, by simultaneously detecting the two energy intervals problems of movements between exposures are reduced.

Fig. 5 shows a schematic, partly enlarged, cross sectional view
10   of a particular embodiment of the invention, taken along A-A of Fig. 1, and shows particularly the avalanche amplification means in more detail. It shall, however, be appreciated that the present invention is not limited to such a design. Other possible avalanche amplification means designs are further elaborated in
15   our copending Swedish patent application No. 9901325-2 entitled *Radiation detector, an apparatus for use in planar radiography and a method for detecting ionizing radiation* and filed on April 14, 1999, which application hereby is incorporated by reference. It shall also be appreciated that the avalanche amplification
20   means may be a solid-state device or comprise a liquid amplification region.

The first electrode arrangement 17 comprises a dielectric substrate 41 and a conductive layer 43 being a cathode electrode, and the second electrode arrangement 21 being the same
25   arrangement as the avalanche cathode 25. The avalanche anode 27 comprises a dielectric substrate 45 and conductive layer strips 47.

A dielectric 49 is arranged between the avalanche cathode 25 and the avalanche anode 27. This could be a gas or a solid substrate
30   49 carrying the cathode 25 and the anode 27, as shown in the Figure. A first voltage is applied between arrangement 17 and arrangement 21, 25 by means of a DC power supply (not shown in Fig. 5) and a second voltage is applied between cathode 25 and

anode 27 such that an electric field 51 is achieved, which is very strong in gas-filled avalanche amplification regions 53. The avalanche regions 53 are formed in a region between and around the edges of the avalanche cathode 25 which are facing each

5    other, and between the avalanche cathode 25 and the avalanche anode 27, where a concentrated electric field will occur due to the applied voltages.

The voltages applied are selected so that a weaker electric field, drift field, is created over the first section of chamber

10   13. Electrons (primary and secondary electrons) released by interaction, e.g. at 35, will drift, due to the drift field, towards the avalanche amplification means. They will enter the very strong avalanche amplification field and be accelerated. The accelerated electrons will interact with other gas atoms in one

15   of regions 53, causing further electron-ion pairs to be produced. Those produced electrons will also be accelerated in the field, and will interact with new gas atoms, causing further electron-ion pairs to be produced. This process continues during the travel of the electrons in the avalanche region towards the anode

20   27 and an electron avalanche is formed.

The avalanche regions 53 are formed by openings or channels in cathode 25 and the dielectric substrate 49, if present. The openings or channels can be of arbitrary shape, e.g. circular or square, as seen from above, or continuous, longitudinal extending

25   between two edges of the substrate 49, if present, and cathode 25. In the case the openings or channels are circular when seen from above they are arranged in rows, each row of openings or channels including a plurality of circular openings or channels. A plurality of longitudinal openings or channels or rows of

30   channels are formed beside each other, parallel with each other or with the incident X-rays. Alternatively, the openings or channels can be arranged in other patterns.

Conductive layer strips 47 also forms read-out elements of read-out arrangement 29. The strips are arranged in connection with the openings or channels forming the avalanche regions 53. Preferably one strip is provided for each opening or channel or

5      row of openings or channels. The strips could be divided into sections along its length, where one section could be provided for each opening or channel or for a plurality of openings or channels, in the form of pads, see further discussion below. The strips and the sections, if present, are electrically insulated

10    from each other. Each detector electrode element i.e. strip or section is preferably separately connected to processing electronics (not shown in Fig. 5).

By providing a plurality of readout strips 47 as shown in Fig. 5 a detector 9 is achieved, wherein electron avalanches derivable

15    mainly from ionization by transversely separated portions of the planar radiation beam are separately detectable. Hereby, one-dimensional imaging may be performed using detector 9.

Alternatively the read-out elements can be located on the backside of the substrate. In this case it is necessary that the

20    anode electrodes 4, 19 are semi-transparent to induced pulses. In connection with Fig. 6 below different possible arrangements of read-out elements are shown.

As an example, the longitudinal channels can have a width in the range 0.01-1 mm, the channels can have a width in the range 0.01-

25    1 mm, and the thickness of the dielectric 49 (separation between avalanche cathode 25 and anode 27) is in the range 0.01-1 mm.

Alternatively, conductive layers 43 and 47 can be replaced by a resistive carrier of e.g. silicon, conductive glass or diamond, and dielectric substrates 41 and 45 can be replaced by conductive

30    layers.

A cross-sectional view taken parallel with A-A in Fig. 1, but in the second section of chamber 13 would be identical to the one

shown in Fig. 5, except of that the gap constituting chamber 13 would be considerably larger. By providing separate readout strips beneath the respective sections of chamber 13 a detector 9 is achieved, wherein electron avalanches derivable mainly from 5 ionization by X-rays of different energy are separately detectable.

In the embodiment described above particular locations of the detector anode and cathode arrangements have been described. There are, however, a plurality of other locations that are 10 equally well suitable in connection with the present invention.

Referring now to Fig. 6, a possible configuration of an avalanche anode arrangement 27 (and read-out arrangement 29) is shown. The arrangement is formed by conductive strips 47 and 63.

A plurality of strips 47 are placed side by side and a plurality 15 of strips 63 are placed side by side, the strips 47, 63 extending in directions parallel to the direction of incident X-ray photons 65, originating from source 3, at each location. Preferably, strips 47 are arranged beneath the first section chamber and strips 63 are arranged beneath the second chamber section. The 20 strips are formed on a substrate, electrically insulated from each other, by leaving a space between them (not shown in Fig. 6). The strips may be formed by photolithographic methods or electroforming, etc.

The space and the width of the strips 47 are adjusted to the 25 specific detector in order to obtain the desired (optimal) spatial resolution. Thus, strips 63 are wider than strips 47, as the spatial resolution achievable anyhow is worse for the higher-energy X-rays.

The strips 47 should be placed under the openings or channels or 30 rows of openings or channels as shown in Fig. 5. Similarly, strips 63 should be placed under corresponding openings or

channels or rows of openings or channels formed in the avalanche amplification means beneath the second chamber section.

Each of the strips 47, 63 is connected to the processing electronics (not shown in Fig. 6) by means of a separate signal
5   conductor, where the signals from each strip preferably are processed separately. If anode or cathode strips constitute the detector strips, the signal conductors also connects the respective strip to the high voltage DC power supply, with suitable couplings for separation.

10  As indicated in Fig. 6, the strips 47, 63 are aiming at the X-ray source 3, which provides compensation for parallax errors in detected images.

In the case the read-out arrangement 29 is a separate arrangement, the anode electrode 27 can be formed as a unitary
15  electrode without strips and spacings.

An alternative configuration of a read-out arrangement (not illustrated) has the strips 47 and/or 63 further divided into segments in the direction of the incident X-rays, the segments being electrically insulated from each other. Preferably a small
20  spacing extending perpendicular to the incident X-rays is provided between each segment of respective strip. Each segment is connected to the processing electronics by means of a separate signal conductor, where the signals from each segment preferably are processed separately.

25  This read-out arrangement can be used when further energy-resolved detection of the X-rays is required. By statistical methods one can restore the spectrum of the incident photons with good energy resolution. See for example E.L. Kosarev et al., Nucl. Instr and methods, 208 (1983) 637, and G.F. Karabadjak et
30  al., Nucl. Instr and methods, 217 (1983) 56.

Generally for all embodiments, each incident X-ray photon causes one induced pulse in one (or more) detector electrode element. The pulses are processed in the processing electronics, which eventually shapes the pulses, and integrates or counts the pulses

5    from each strip (pad or sets of pads) representing one picture element. The pulses can also be processed so as to provide an energy measure for each pixel.

Where the detector electrode is on the cathode side, the area of

10   an induced signal is broader (in a direction perpendicular to the direction of incidence of the X-ray photons) than on the anode side. Therefore, weighing of the signals in the processing electronics is preferable.

Fig. 7 shows schematically a device 91 according to an embodiment

15   of the present invention having a plurality of the inventive detectors 9 stacked, side-by-side of each other. By this embodiment multiline scan can be achieved, which reduces the overall scanning distance, as well as the scanning time. The device of this embodiment includes an X-ray source 3, which

20   together with a number of collimator windows 5 produce a number of planar fan-shaped X-ray beams 1, for irradiation of the object 7 to be imaged. The beams transmitted through the object 7 optionally enter the individual stacked detectors 9 through a number of second collimator windows 11, which are aligned with

25   the X-ray beams. The first collimator windows 5 are arranged in a first rigid structure (not shown in Fig. 7), and the optional second collimator windows 11 are arranged in a second rigid structure (not shown in Fig. 7) attached to the detectors 9, or arranged separately on the detectors.

30   The X-ray source 3, the first rigid structure, and the possible second rigid structure including collimator windows 11, respectively, and the stacked detectors 9, which are fixed to each other, are connected and fixed in relation to each other by a certain means, e.g. a frame or support (not shown in Fig. 7).

The so formed device for radiography can be moved as a unit to scan an object, which is to be examined. In this multiline configuration, the scanning can be done in a transverse movement, perpendicular to the X-ray beam, as mentioned above. It can also

5   be advantageous if the device for radiography is fixed and the object to be imaged is moved. Alternatively, the collimator and the detector can be moved synchronously by a commonly controlled motor.

A further advantage of using a stacked configuration, compared to

10  large single volume gas detectors, is reduction of background noise caused by X-ray photons scattered in the object 7. These scattered X-ray photons travelling in directions not parallel to the incident X-ray beam could cause "false" signals or avalanches in one of the other detectors 9 in the stack, if passing through

15  anode and cathode plates and entering such a chamber. This reduction is achieved by significant absorption of (scattered) X-ray photons in the material of the anode and the cathode plates, or the collimator 11.

This background noise can be further reduced by providing thin

20  absorber plates (not illustrated) between the stacked detectors. These absorber plates or sheets can be made of a high atomic number material, for example tungsten.

It is general for all embodiments that the gas volumes are very thin, which results in a fast removal of ions, which leads to low

25  or no accumulation of space charges. This makes operation at high rate possible.

It is also general for all embodiments that the small distances leads to low operating voltages, which results in low energy in possible sparks, which is favorable for the electronics.

30  The focusing of the field lines in the embodiments is also favorable for suppressing streamer formations. This leads to a reduced risk for sparks.

As an alternative for all embodiments, the electric field in the conversion and drift gap (volume) can be kept high enough to cause electron avalanches, hence to be used in a pre-amplification mode.

5   As a further alternative, the electrode arrangement 21, 25 may be dispensed with, and an electric field between electrode arrangement 17, 19 and cathode arrangement 27 can be kept high enough to cause electron avalanche amplification within the complete volume as defined by regions 13 and 23, 53.

10  Further, all electrode surfaces may be covered by a resistive material in order to decrease the risk for occurrence of sparks, which will influence the measurement and may destroy electronic equipment of the detector. Such resistive layers are further described in our copending Swedish patent application No.
15  9901327-8 entitled *Radiation detector and an apparatus for use in radiography* and filed on April 14, 1999. The application is hereby incorporated by reference.

It will be obvious that the invention may be varied in a plurality of ways. For example, the voltages can be applied in
20  other ways as long as the described electrical fields are created.

Such variations are not to be regarded as a departure from the scope of the invention. All such modifications as would be obvious to one skilled in the art are intended to be included
25  within the scope of the appended claims.

## CLAIMS

1. A detector for detection of ionizing radiation, comprising:
- a chamber (13) filled with an ionizable gas, and including a first (17, 19) and a second (21) electrode arrangement,
5  substantially in parallel with each other, between which a first voltage $(U_1, U_2)$ is applicable,
- a radiation entrance (33) arranged such that radiation (1) can enter the chamber between and substantially in parallel with the first and second electrode arrangements, for ionization of the
10  ionizable gas,
- an electron avalanche amplification means (15) including an avalanche cathode arrangement (25) and an avalanche anode arrangement (27), between which a second voltage $(U_a)$ is applicable, and
15  - a read-out arrangement (29), wherein
- the first voltage is applicable for drifting electrons created during ionization towards the electron avalanche amplification means, the second voltage is applicable for avalanche amplification of said electrons, and the read-out arrangement is
20  arranged for detection of electron avalanches and/or correspondingly produced ions,
c h a r a c t e r i z e d   i n   that
- the chamber is arranged such that radiation entering through the radiation entrance will firstly enter a first chamber section
25  having a first distance $(d_1)$ between the first and second electrode arrangements and then enter a second chamber section having a second distance $(d_2)$ between the first and second electrode arrangements, the first $(d_1)$ and second $(d_2)$ distances being substantially different, and
30  - the read-out arrangement is arranged such that electron avalanches, and/or correspondingly produced ions, derivable mainly from ionization in the respective chamber section are separately detectable.

2. The detector as claimed in Claim 1, wherein the first distance $(d_2)$ is shorter than the attenuation length of fluorescent photons emitted in the ionizable gas subsequent to ionization.

3. The detector as claimed in Claim 1 or 2, wherein the first distance $(d_1)$ is shorter than the second distance $(d_2)$.

5

4. The detector as claimed in any of the preceding Claims, wherein the second distance $(d_2)$ is shorter than the attenuation length of fluorescent photons emitted in the ionizable gas subsequent to ionization.

10

5. The detector as claimed in any of the preceding Claims, wherein the radiation entrance (33) is arranged such that radiation having a broadband energy spectrum can enter the chamber, whereby short-range electrons are released through ionization by lower energy radiation and long-range electrons are

15 released through ionization by higher energy radiation; and wherein the first distance $(d_1)$ is shorter than the interaction length of the long-range electrons.

6. The detector as claimed in Claim 5, wherein the first distance $(d_2)$ is shorter than a few times the interaction length electron

20 of the short-range electrons.

7. The detector as claimed in Claim 5 or 6, wherein the second distance $(d_2)$ is shorter than a few times the interaction length electron of the long-range electrons.

8. The detector as claimed in any of Claims 5-7, wherein the

25 first and second chamber sections are separated in a fluid-tight, but radiation permeable, manner and each chamber is individually filled with an ionizable gas of a predetermined pressure.

9. The detector as claimed in any of Claims 5-8, wherein the ionizable gas and the length $(l_1, l_2)$ of the respective chamber

30 section in the direction of the incident X-rays are arranged such that a substantial portion of the lower energy radiation is

absorbed in the first chamber section and a substantial portion of the higher energy radiation is absorbed in the second chamber section, whereby the read-out element arrangement (29) is arranged for energy-resolved detection of the radiation.

5      10. The detector as claimed in any of claims 1-9, wherein the first and second electrode arrangements are planar.

11. The detector as claimed in any of the preceding Claims, wherein the radiation entrance (33) is arranged such that a planar radiation beam (1) can enter the chamber, and the read-out

10     arrangement (29) is provided with a plurality of readout strips (47, 63) placed side by side and extending in directions parallel to the directions of said planar radiation beam at each location, such that electron avalanches, and/or correspondingly produced ions, derivable mainly from ionization by transversely separated

15     portions of said planar radiation beam are separately detectable.

12. The detector as claimed in any of the preceding Claims, further comprising a signal processing means arranged for discriminating a signal derivable from detected electron avalanches, and/or correspondingly produced ions, in dependence

20     on a signal derived parameter.

13. The detector as claimed in any of the preceding Claims, wherein the electron avalanche amplification means (15) comprises a plurality of avalanche regions (53).

14. The detector as claimed in Claim 13, wherein the avalanche

25     cathode arrangement (25) is provided with openings.

15. The detector as claimed in Claim 13 or 14, wherein the avalanche anode arrangement (27) is provided in the form of a plurality of strips (47, 63) or pads.

16. The detector as claimed in any of the preceding Claims,

30     wherein the second electrode arrangement (21) and the avalanche cathode arrangement (25) are comprised of a single arrangement.

17. The detector as claimed in any of the preceding Claims, wherein the avalanche anode arrangement (27) and the read-out arrangement (29) are comprised of a single arrangement.

18. A device for use in planar beam radiography,
5  c h a r a c t e r i z e d  i n  that it comprises an X-ray source (3), means (5) for forming an essentially planar X-ray beam (1) located between said X-ray source and an object (7) to be imaged, and the detector (9) as claimed in any of the preceding Claims located and arranged for detection of the planar X-ray beam as
10 transmitted through or reflected off said object.

19. The device as claimed in Claim 18, wherein said X-ray source (3), said means (5) for forming an essentially planar X-ray beam (1) and said detector (9) are fixed in relation to each other.

20. The device as claimed in Claim 18 or 19, comprising a
15 second and a further of the detector (9) as claimed in any of Claims 1-17, which detectors are stacked to form a detector unit, and means (5) for forming an essentially planar X-ray beam (1) for each detector, said means being located between said X-ray source (3) and said object (7), wherein each detector is
20 located and arranged for detection the respective planar X-ray beam as transmitted through or reflected off said object.

21. The device as claimed in Claim 20, comprising absorber plates arranged between the detectors (9) in order to absorb scattered X-ray photons.

25 22. A method for detection of ionizing radiation in a detector comprising a chamber (13) filled with an ionizable gas, and including a first (17, 19) and a second (21) electrode arrangement, substantially in parallel with each other, a radiation entrance (33), an electron avalanche amplification
30 means (15) including an avalanche cathode arrangement (25) and an avalanche anode arrangement (27), and a read-out arrangement (29), said method comprising:

- introducing a radiation beam (1) into the chamber between and substantially in parallel with the first and second electrode arrangements, for ionization of the ionizable gas,

- applying a first voltage ($U_1, U_2$) between the first (17, 19) and
5   second (21) electrode arrangements for drifting electrons created during ionization towards the electron avalanche amplification means,

- applying a second voltage ($U_a$) between the avalanche cathode (25) and avalanche anode (27) arrangements for avalanche
10   amplification of said electrons, and

- by means of the read-out arrangement detecting electron avalanches and/or correspondingly produced ions,
c h a r a c t e r i z e d   b y

- firstly introducing the radiation beam (1) into a first section
15   of the chamber having a first distance ($d_1$) between the first and second electrode arrangements and then introducing the radiation beam into a second chamber section having a second distance ($d_2$) between the first and second electrode arrangements, the first ($d_1$) and second ($d_2$) distances being substantially different, and

20   - by means of the read-out arrangement separately detecting electron avalanches, and/or correspondingly produced ions, derivable mainly from ionization in the respective chamber section.

23. The method as claimed in Claim 22, further comprising the
25   step of geometrically discriminating electrons of a predetermined kinetic energy in the chamber (13) by means of selecting the first ($d_1$) or the second ($d_2$) distance in dependence on said predetermined kinetic energy.

24. The method as claimed in Claim 22 or 23, further comprising
30   the step of electronically discriminating electron avalanches, and/or correspondingly produced ions, derivable mainly from radiation of a predetermined energy by means of separating pulses having a signal derived parameter, particularly amplitude or integrated value, corresponding to said predetermined energy.

25. The method as claimed in any of Claims 22-24, further comprising introducing the radiation beam in the form a planar radiation beam (1) into the chamber, and by means of the read-out arrangement (29) separately detecting electron avalanches, and/or

5    correspondingly produced ions, derivable mainly from ionization by transversely separated portions of said planar radiation beam.

26. A detector for detection of ionizing radiation comprising:
- a    chamber (13) filled with an ionizable substance, and including a first (17, 19) and a second (27, 45, 47) electrode

10   arrangement, substantially in parallel with each other;
- a radiation entrance (33) arranged such that radiation (1) can enter the chamber between and substantially in parallel with the first and second electrode arrangements and ionize the ionizable substance;

15   - an electron avalanche amplification means for avalanche amplification of electrons created during ionization; and
- a read-out arrangement (29, 45, 47, 63) for detection of the electron avalanches and/or correspondingly produced ions, c h a r a c t e r i z e d   i n   that

20   - the chamber is arranged such that radiation entering through the radiation entrance will firstly enter a first chamber section having a first distance between the first and second electrode arrangements and then enter a second chamber section having a second distance between the first and second electrode

25   arrangements, the first and second distances being substantially different, and
- the read-out arrangement is arranged such that electron avalanches, and/or correspondingly produced ions, derivable mainly from ionization in the respective chamber section are

30   separately detectable.

27. The detector as claimed in Claim 26, wherein the first distance is shorter than the attenuation length of fluorescent photons emitted in the ionizable gas subsequent to ionization.

28. The detector as claimed in Claim 26 or 27, wherein the first distance is shorter than the second distance.

29. The detector as claimed in any of Claims 26-28, wherein the second distance is shorter than the attenuation length of
5   fluorescent photons emitted in the ionizable gas subsequent to ionization.

30. The detector as claimed in any of the preceding Claims, wherein the radiation entrance (33) is arranged such that radiation having a broadband energy spectrum can enter the
10  chamber, whereby short-range electrons are released through ionization by lower energy radiation and long-range electrons are released through ionization by higher energy radiation; and wherein the first distance $(d_1)$ is shorter than the interaction length of the long-range electrons.

15  31. The detector as claimed in Claim 30, wherein the first distance is shorter than a few times the interaction length electron of the short-range electrons.

32. The detector as claimed in Claim 30 or 31, wherein the second distance is shorter than a few times the interaction length
20  electron of the long-range electrons.

33. The detector as claimed in any of Claims 30-32, wherein the first and second chamber sections are separated in a fluid-tight, but radiation permeable, manner and each chamber is individually filled with an ionizable substance.

25  34. The detector as claimed in any of Claims 30-33, wherein the ionizable substance and the length $(l_1, l_2)$ of the respective chamber section in the direction of the incident X-rays are arranged such that a substantial portion of the lower energy radiation is absorbed in the first chamber section and a
30  substantial portion of the higher energy radiation is absorbed in the second chamber section, whereby the read-out element

arrangement (29) is arranged for energy-resolved detection of the radiation.

35. The detector as claimed in any of claims 26-34, wherein the first and second electrode arrangements are planar.

5    36. A device for use in planar beam radiography, c h a r a c t e r i z e d  i n  that it comprises an X-ray source (3), means (5) for forming an essentially planar X-ray beam (1) located between said X-ray source and an object (7) to be imaged, and the detector (9) as claimed in any of the preceding Claims

10   located and arranged for detection of the planar X-ray beam as transmitted through or reflected off said object.

37. A method for detection of ionizing radiation in a detector comprising a chamber (13) filled with an ionizable substance, and including a first (17, 19) and a second (27, 45, 47) electrode

15   arrangement, substantially in parallel with each other, a radiation entrance (33), an electron avalanche amplification means (15), and a read-out arrangement (29, 45, 47, 63), said method comprising:
- introducing a radiation beam (1) into the chamber between and

20   substantially in parallel with the first and second electrode arrangements, for ionization of the ionizable substance, and
- avalanche amplifying the electrons created during ionization, c h a r a c t e r i z e d  b y
- firstly introducing the radiation beam (1) into a first section

25   of the chamber having a first distance $(d_1)$ between the first and second electrode arrangements and then introducing the radiation beam into a second chamber section having a second distance $(d_2)$ between the first and second electrode arrangements, the first $(d_1)$ and second $(d_2)$ distances being substantially different, and

30   - by means of the read-out arrangement separately detecting electron avalanches, and/or correspondingly produced ions, derivable mainly from ionization in the respective chamber section.

34

38. The method as claimed in Claim 37, further comprising geometrically discriminating electrons of a predetermined kinetic energy in the chamber (13) by means of selecting the first $(d_1)$ or the second $(d_2)$ distance in dependence on said predetermined

5    kinetic energy.

39. The method as claimed in Claim 37 or 38, further comprising electronically discriminating electron avalanches, and/or correspondingly produced ions, derivable mainly from radiation of a predetermined kinetic energy by means of separating pulses

10   having a signal derived parameter, particularly amplitude or integrated value, corresponding to said predetermined energy.
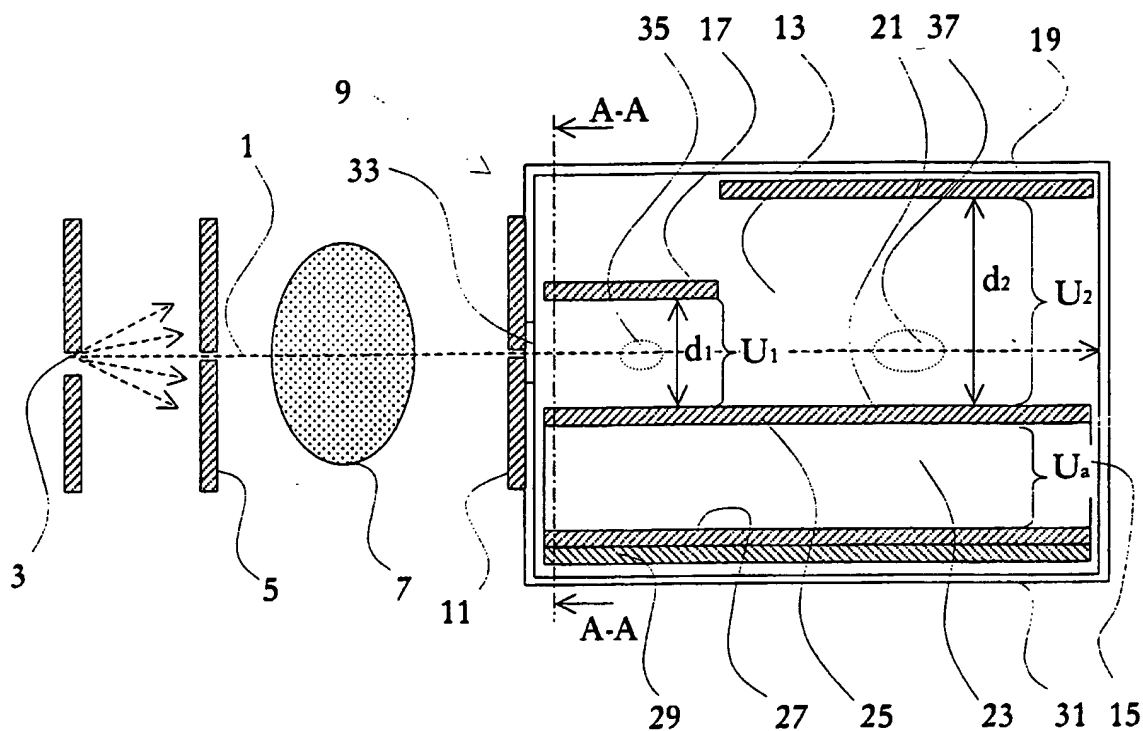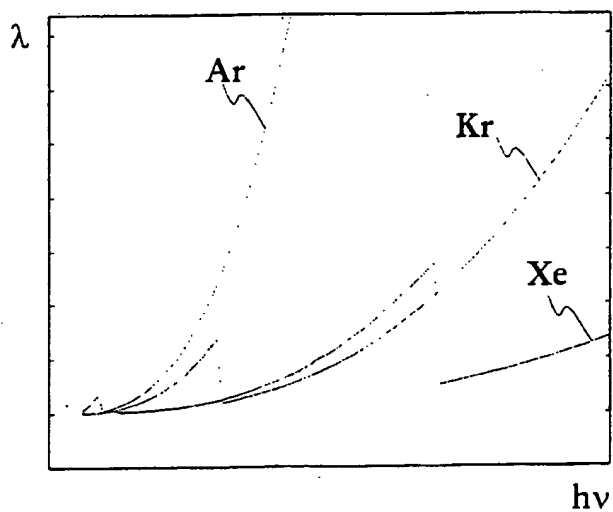
## 1/4



# Fig. 1



# Fig. 2

## 2/4



Fig. 3



Fig. 4

3/4



Fig. 5



Fig. 6

4/4

91

9

1

3

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7

11
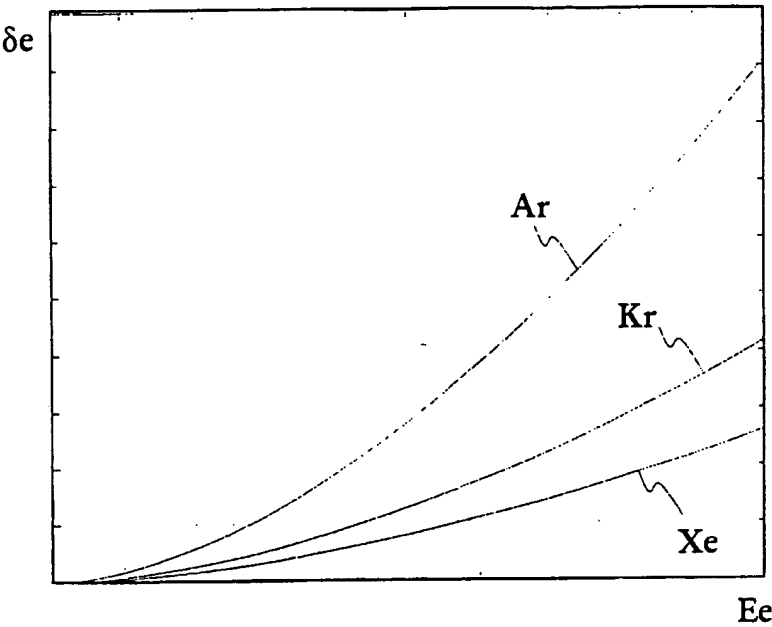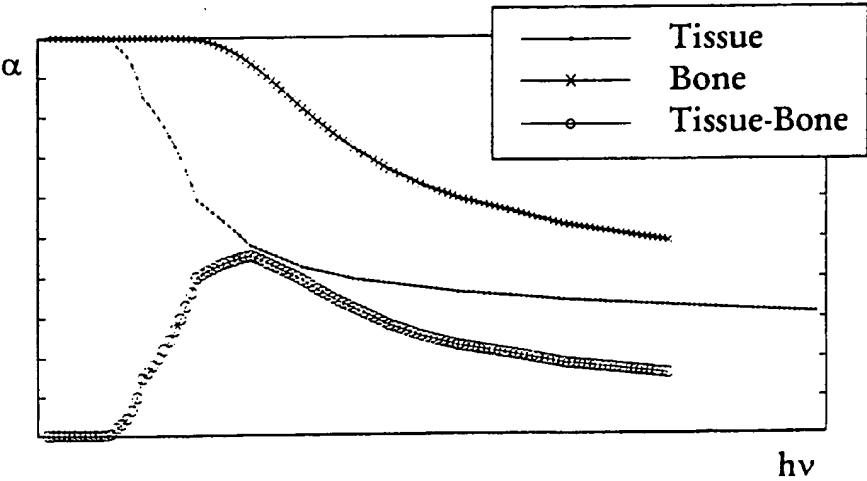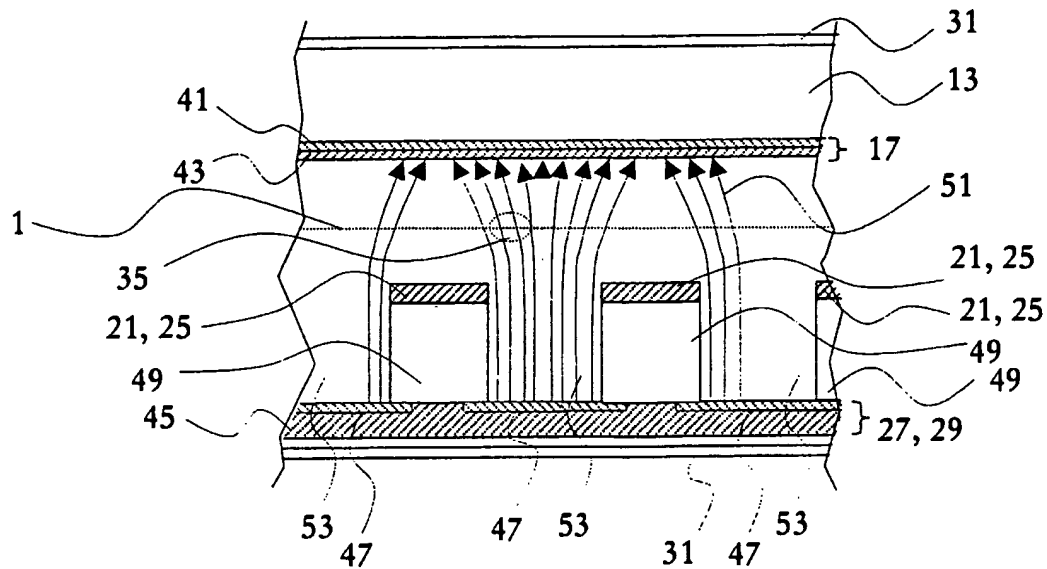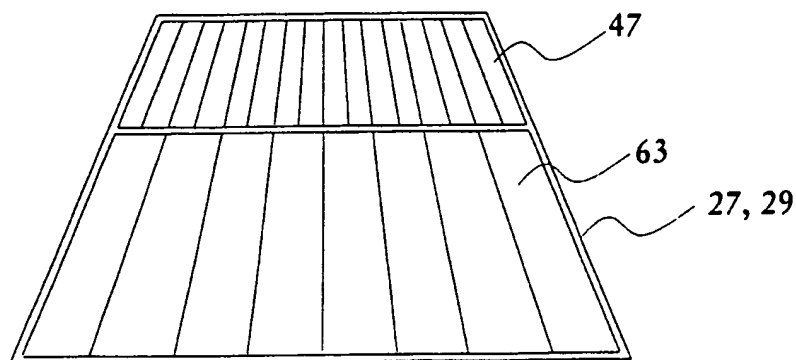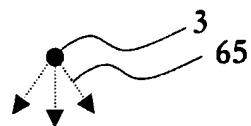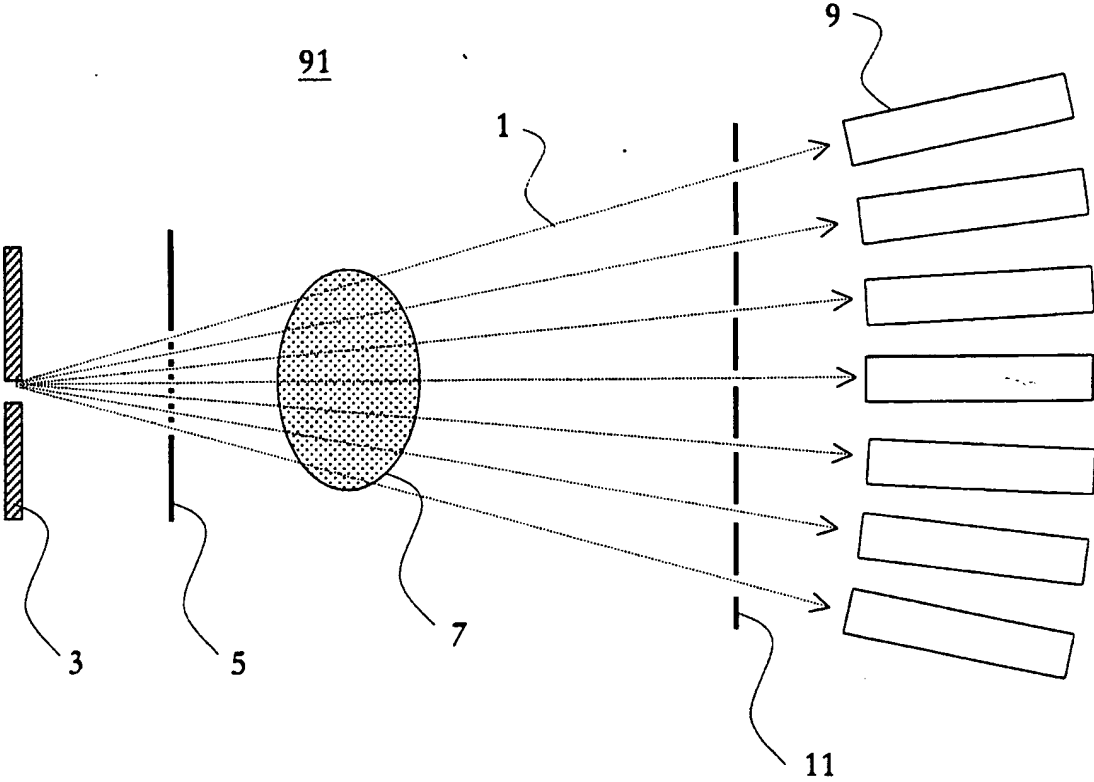
# Fig. 7

## INTERNATIONAL SEARCH REPORT

| | |
|---|---|
| | International application No. |
| | PCT/SE 01/00054 |

**A. CLASSIFICATION OF SUBJECT MATTER**

**IPC7: G01T 1/185, H01J 47/02**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

**IPC7: G01T, H01J**

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

**SE,DK,FI,NO classes as above**

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document. with indication. where appropriate. of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | NL 7703944 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN), 16 October 1978 (16.10.78), figures 1,5 | 1,11,12, 18-20,22,25 |
| Y | | 2-10,13-17, 21,23,24 |
| | -- | |
| Y | US 4461953 A (ROBERT ALLEMAND ET AL), 24 July 1984 (24.07.84), column 3; column 4, figures 1,2 | 2-10,13-17, 21,23,24 |
| | -- | |
| A | US 5521956 A (GEORGES CHARPAK), 28 May 1996 (28.05.96), column 6, line 33 - line 67 | 1-25 |
| | -- | |

[X] Further documents are listed in the continuation of Box C.          [X] See patent family annex.

| | |
|---|---|
| * Special categories of cited documents: | "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
| "A" document defining the general state of the art which is not considered to be of particular relevance | |
| "E" earlier application or patent but published on or after the international filing date | "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone |
| "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| "O" document referring to an oral disclosure, use, exhibition or other means | |
| "P" document published prior to the international filing date but later than the priority date claimed | "&" document member of the same patent family |

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 22 May 2001 | 3 0 -05- 2001 |
| Name and mailing address of the ISA· Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86 | Authorized officer Sture Elnäs/MN Telephone No. +46 8 782 25 00 |

Form PCT/ISA/210 (second sheet) (July 1998)

## INTERNATIONAL SEARCH REPORT

| International application No. |
|---|
| PCT/SE 01/00054 |

C (Continuation).   DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 4260895 A (RUDOLF SCHITTENHELM), 7 April 1981 (07.04.81), column 2, line 3 - line 13<br><br>--<br>-------- | 1-25 |

## INTERNATIONAL SEARCH REPORT

International application No.
**PCT/SE 01/00054**

| Box I | Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet) |
|---|---|

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: **26-39**
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

   **See next page**

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

| Box II | Observations where unity of invention is lacking (Continuation of item 2 of first sheet) |
|---|---|

This International Searching Authority found multiple inventions in this international application. as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant. this international search report covers only those claims for which fees were paid. specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently. this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**      ☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (1)) (July1998)

## INTERNATIONAL SEARCH REPORT

| International application No. |
|---|
| **PCT/SE 00054** |

Claims 26-39 relate to a device and a method for measuring ionizing radiation by means of a chamber filled with an ionizable substance. The claims cover in general any substance, whereas the application provide support within the meaning of Article 6 PCT and disclosure within the meaning of Article 5 PCT for only a few ionizable gases. Therefore, a novelty search covering the whole claimed scope is not possible.

Consequently, the search performed is only considered to cover the embodiments described in the application.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established will not be the subject of an intentional preliminary examination (Rule 66.1(e) PCT). This is the case irrespective of whether or not the claims are amended following receipt of the search report during any Chapter II procedure.

Form PCT/ISA/210 (extra sheet) (July 1998)

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